Chapter

4

Seismic Design and Evaluation Requirements for DOE Facilities

FOREWORD: The Facility Manager's Perspective

Donald G. Eagling

In December 1992, DOE Order 5480.28[*] (Ref. 1) covering *Natural Phenomena Hazards Mitigation* (NPH) was approved by the U.S. Department of Energy (DOE) Offices of Environment, Safety, and Health and Nuclear Energy. It was issued by the Secretary of Energy in January 1993. The Order states that it is the policy of the U.S. Department of Energy to design, construct, and operate DOE facilities so that workers, the general public, and the environment are protected from the impacts of natural phenomena hazards. It established new and more comprehensive protection against earthquakes, extreme winds, tornadoes, and flood hazards for all DOE facilities. It is consistent with the *National Earthquake Hazards Reduction Program* (NEHRP) and the President's Executive Orders on Seismic Safety. There are two Executive Orders; 12699 covering new building construction (Ref. 2), and 12941 covering existing buildings (Ref. 3).

The landmark policy embodied in DOE Order 5480.28 represented the culmination of 20 years of leadership by the department in the continuous development of improved seismic safety This policy has for its implementation a series of DOE Standards that were developed under the Office of Environment, Safety and Health with major support from the Lawrence Livermore National Laboratory, other DOE contractors and specialized consultants from the private sector. Order 5480.28 included extensive input and widely based concurrence by more than 50 DOE and contractor organizations.

Chapter 4a provides a road map for architects, engineers, and managers who must utilize DOE Order 5480.28 and its implementing standards to ensure seismic safety within the DOE complex. A summary of the DOE NPH Mitigation Policy and Standards is provided in Chapter 4b. Although the new DOE Orders and

[*] This document was completed in October 1995, at that time DOE was in the process of consolidating orders. DOE Order 5480.28, *Natural Phenomena Hazards Mitigation,* was being combined with three other orders to form a new DOE Order 420.1, Facility Safety. In addition, the draft *Corporate Facilities Management Order* has cancelled DOE Order 6430.1A.
A Natural Phenomena Rule, 10 CFR 830.215 and accompanying Safety Guide was also being drafted. These new directives retain the information contained in DOE Order 5480.28. DOE Standards 1020 through 1024 will continue to be referenced by the new directives.

Standards are comprehensive in that they cover earthquakes, extreme winds, tornadoes, flood hazards, and other natural hazards, this *Seismic Safety Manual* focuses on seismic safety only.

The overall approach for DOE NPH Mitigation is to provide protection against the impact of natural hazards graded in proportion to the consequences of failure of its facilities (including the potential release of hazardous material). *Facilities* include buildings, other structures, programmatic and process equipment, subsystems, infrastructure, and their individual components, all of which are referred to as *Structures, Systems, and Components* (SSCs) in NPH Orders and Standards. This approach is consistent with DOE's *Safety Analysis Reports* (SAR), which evaluate and classify each DOE building or facility by the level of potential hazard it presents based upon accident analysis.

The consequences of failure of a building (or SSC) affected by an earthquake depend upon the type of failure (e.g., catastrophic collapse versus bent out of shape), the occupancy within the building (e.g., people, process equipment, hazardous materials, etc.), the potential for loss of life or loss of use, and the impact on the public or the environment. Depending upon the results of a risk analysis, an individual facility (or SSC) is placed into one of five *Performance Categories* (PCs) that range from PC-0 to PC-4, each of which has defined performance goals. An SSC can be placed in category PC-0 only if the consequences of failure are none or negligible with respect to safety. Performance goals for categories PC-1 to PC-4 range from those required for ordinary occupancies to those required for facilities that pose a potential hazard to the public and the environment because radioactive or highly toxic materials could be released in the event of loss of confinement.

The performance goals for PC-1 and PC-2 are generally the same as those achieved if the provisions of *Uniform Building Code* (UBC) (Ref. 4) are followed for *Standard Occupancy Structures* and *Essential Facilities*, respectively. *Essential Facilities* generally include hospitals, fire and police stations, emergency operations centers (EOC), and supporting systems such as water tanks, emergency generators, communications centers, etc., that must continue to function in the aftermath of an earthquake. Also a facility (or SSC) may be designed to meet UBC requirements for *Essential Facilities* because it is of greater importance due to mission-dependent considerations or because it may pose a greater danger to occupants or other on-site personnel than *Standard Occupancy Structures*.

It should be noted that the intent of this *Seismic Safety Manual* is to focus primarily on conventional facilities that may adhere to the requirements of the UBC for *Standard Occupancy Structures* (PC-1) or *Essential Facilities* (PC-2) rather than those in categories PC-3 and -4. It is, however, necessary to explain all five categories in Chapter 4 so that readers have some understanding of the full nature and range of DOE's seismic safety policy and regulations. Only a small percentage of DOE facilities fall into PC-3 or PC-4. The seismic provisions for PC-3 are consistent with those used to design (or reevaluate) commercial plutonium facilities with conservatism greater than required by the UBC for *Essential Facilities* and less than required for civilian nuclear power plants. The seismic provisions for PC-4 approach those used to design (or reevaluate) civilian nuclear power plants.

The concept for graded performance provisions is to:

1. Estimate the level of intensity of shaking that will probably occur at a given site.

2. Categorize each of the site facilities (SSC's) (existing or proposed) into one of the five categories, PC-0 through PC-4, based upon its usage (or potential risk in the event of failure).

3. Evaluate existing facilities and design new facilities (or strengthen existing facilities) to meet the seismic and quality control standards required for the assigned Performance Category (PC).

The seismic and quality control standards required to meet the performance goals of each category are set to ensure that the likelihood of failure (as measured by the onset of structural distress or the onset of loss of function) is appropriate for the consequences of failure.

The earthquake loading for each site is defined at a level corresponding to its specified annual probability of occurrence, which is related to the average return period of the design earthquake. The longer the average return period, the greater the design earthquake loading, and the less likely that loading will be exceeded in any one year. In essence, the input earthquake forces are defined on the basis of a specified annual probability that the design load will be exceeded.

Because experiences with *individual* earthquakes often surprise experts (and relate rather poorly to statistical averages), selection of earthquake loads is not a precise process even when large amounts of time and money are expended to investigate a given site. Probability analysis cannot be relied upon to pinpoint future earthquake loadings. Probability does, however, provide a reasonable basis for defining a level of loading compatible with risk calculations, given that both are based on probability assumptions.

From the structural engineer's point of view (and concern for liability), the idea that design loadings may be exceeded is not very inviting. The engineer-of-record for a given project would prefer to design a facility that will be safe under the most severe earthquake.

Fortunately, DOE seismic Standards incorporate conservative design and evaluation procedures, safety factors, and quality control measures that can be relied upon to ensure a specific level of seismic resistance based on known technology commonly practiced in the structural engineering profession. This *deterministic* level of seismic resistance in turn can be related to the target performance goals of each performance category and defined at a specified *seismic hazard exceedance probability* so that performance loads and risk probabilities can be related. In this way, the design (or evaluated) capacity can be compared in the same probabilistic terms as the risk analysis. This provides a practical methodology for setting performance standards appropriate to the hazard or to the consequences of failure due to the hazard.

It is one thing to accurately design for a given level of seismic resistance; it is another, and more difficult task, to accurately predict the specific level of loading at which failure will occur. Fortunately, it is practical to design a structure so that the mode of failure (if it ever happens) is ductile and not catastrophic. This concept is incorporated in the seismic provisions of the DOE Standards as well as those in the UBC. Consequently, deterministic techniques, not probabilistic, are used to further enhance seismic safety for facility occupants, the public, and the environment.

For facility managers, as well as structural engineers, the concept of seismic loadings and risk measurement in terms of *hazard exceedance probability* may be difficult to understand. However, in practice, the use of hazard assessment in terms of probability is neither rigorous nor very complex. It is simply a means of setting graded seismic input loads for normal structural analysis and design that are reasonably appropriate for the risks presented by the hazards involved.

A familiar application of this concept is embodied in the UBC to determine the minimum seismic forces for designing *Standard Occupancy Structures* and *Essential Facilities* that correspond to graded DOE Performance Categories PC-1 and -2, respectively. Seismic input forces are determined by the type of structural system, the facility's importance (standard occupancy or essential facility), and the probable intensity of ground shaking that may occur at the location of the site. For a given site, a "Z" factor is selected from a seismic zone map of the United States and applied to the seismic input based on the probability that an earthquake of a given intensity will occur there within a given period of years. This seismic zone map has been probability-based since the 1988 edition of the UBC.

For *Essential Facilities* that are necessary for emergency operations during and after a natural disaster such as an earthquake, the UBC applies an importance factor of 1.25 to the input base shear required for *Standard Occupancy Structures*. This factor, together with other provisions of the code that also add conservatism for *Essential Facilities*, significantly decreases the probability that the designed structure will suffer damage resulting in loss of function.

The UBC, like the DOE seismic Standards, provides seismic input loadings that are probabilistic-based, and require rigorous analysis and conservative design techniques to ensure that seismic resistance encompasses the potential deviations of the less precise probabilistic input.

The specifications of seismic hazard required by DOE are appropriate as long as the seismic design (or evaluation) of the SSCs for these earthquake levels is conservatively performed. The level of conservatism (or level of loading) should increase as one goes from PC-1 to PC-4. The criteria contained in DOE seismic Standards follow the philosophy of a gradual reduction in the probability that the design earthquake will be exceeded coupled with a gradual increase in the conservatism of analysis and design requirements going from PC-1 toward PC-4.

DOE Order 5480.28 includes a schedule for implementation of its supporting Standards, DOE-1020 through DOE-1024. These requirements are effective immediately for all new sites or new facilities. For existing facilities, it is required that an implementation plan for evaluation and upgrading be completed and submitted to DOE within one year of the effective date of the last Standard to be issued (Refs. 5 through 9). This plan must include a prioritized schedule for the sequence of evaluation and upgrade of existing facilities. Exemptions require DOE headquarters approval. Deviations may be granted by headquarters where it can be demonstrated that the deviation provides seismic protection equivalent to the DOE Standards.

A recent review by the Federal Emergency Management Agency (FEMA) found, *"At the DOE, an exemplary program has been established that contains all the elements of an agency seismic safety program. The DOE program can serve as the model for other agencies in leadership and program implementation activities of Executive Order 12699."*

References

1. *Natural Phenomena Hazards Mitigation*, DOE Order 5480.28, U.S. Department of Energy, Washington, D.C., January 15, 1993.
2. *Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction*, Executive Order 12699, Washington, D.C., January 5, 1990.
3. *Seismic Safety of Existing Federally Owned or Leased Buildings*, Executive Order 12941, Washington, D.C., December 1, 1994.
4. *Uniform Building Code*, International Conference of Building Officials, Whittier, California, 1994.
5. *Natural Phenomena Hazards Design and Evaluation for Department of Energy Facilities*, DOE-STD-1020-94, U.S. Department of Energy, Washington, D.C., April 1994.
6. *Performance Categorization Criteria for Structures, Systems, and Components at DOE Facilities Subjected to Natural Phenomena Hazards*, DOE-STD-1021-93, U.S. Department of Energy, Washington, D.C., July 1993.
7. *Natural Phenomena Hazards Site Characterization Criteria*, DOE-STD-1022-94, U.S. Department of Energy, Washington, D.C., March 1994.
8. *Natural Phenomena Hazards Assessment Criteria*, DOE-STD-1023-95, U.S. Department of Energy, Washington, D.C., September 1995.
9. *Guidelines for Use of Probabilistic Seismic Hazard Curves at Department of Energy Sites*, DOE-STD-1024-92, U.S. Department of Energy, Washington, D.C., December 1992.

Chapter

4a

Guidelines for Using DOE Orders and Standards for Earthquake Safety

Frank E. McClure

Introduction

Facilities managers for government-owned contractor-operated (GOCO) facilities, their staffs, and consulting architects and engineers involved with design and evaluation of U.S. Department of Energy (DOE) facilities must be familiar with applicable DOE Natural Phenomena Hazards (NPH) Orders and Standards. The number of interdependent provisions included in these documents may be rather intimidating to those unfamiliar with the DOE system. This chapter provides an overview or *road map* through the many Orders and Standards affecting seismic safety. Added guidance also is presented in terms of resource documents that provide technical information to help comply with these Orders and Standards.

Figure 4a-1 shows the relationship of federal requirements and DOE Orders for seismic safety. Examples of policy documents are Presidential Executive Orders that can be issued with or without congressional mandate. Presidential Executive Order 12699, *Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction* (January 5, 1990), and Executive Order 12941, *Seismic Safety of Existing Federally Owned or Leased Buildings* (December 1, 1994) establish the policy for the seismic design of new and existing buildings, respectively.

Rules formalizing policies are generally published in the *Code of Federal Regulations* (CFR).

DOE Orders are issued to assist in the implementation of policies. DOE Order 5480.28, *Natural Phenomena Hazards Mitigation*, sets forth DOE policy for the development of standards and guidance for designing or evaluating *Structures, Systems, and Components* (SSCs) subject to natural phenomena hazards.

DOE Standards provide technical background and criteria to carry out DOE Orders. Also, national, federal, and industry codes and consensus standards are referenced.

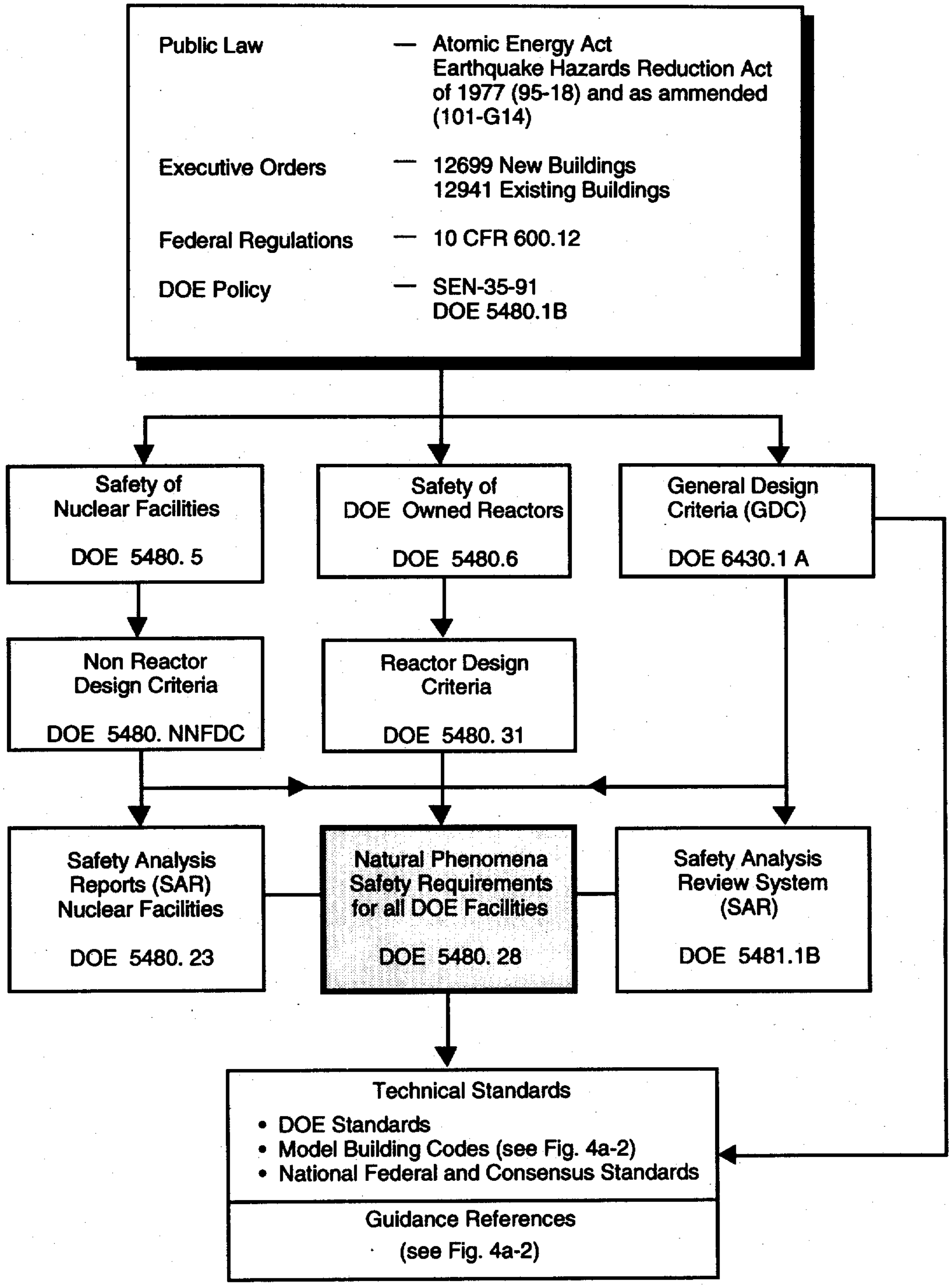

Fig. 4a-1. Relationships of federal requirements and DOE Orders for seismic safety.

Guidance consists of reference documents that address special topic areas to supplement information in the *Standards.*

Figure 4a-2 shows the relationship of standards and guidance used by DOE for seismic safety. Policies and Rules, as well as DOE Orders and Standards, are regulatory in nature. Guidance documents and industry standards, for example, promulgate good practice.

Applicable Executive Orders and DOE Orders and Standards are listed below in logical order, beginning with policy documents, followed by specific Orders, and ending with more detailed Standards.

- Presidential Executive Order 12699, *Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction* , January 1990.
- Presidential Executive Order 12941, *Seismic Safety of Existing Federally Owned or Leased Buildings,* December 1994.
- Interagency Committee on Seismic Safety in Construction (ICSSC), ICSSC RP 2.1-A, *Guidelines and Procedures for Implementation of the Executive Order on Seismic Safety of New Building Construction.*
- DOE Order 5480.1B, *Environment, Safety and Health (ES&H) Program for DOE Operations,* contains the requirements and responsibilities for ES&H programs.
- DOE Order 5480.23, *Nuclear Safety Analysis Reports,* establishes uniform requirements for the preparation and review of safety analysis reports for nuclear facilities.
- DOE Order 5480.28, *Natural Phenomena Hazards Mitigation,* establishes policy and requirements for NPH mitigation to comply with DOE Order 5480.1B. This Order establishes (1) policy requirements for mitigation of NPH at DOE facilities, (2) consistent requirements for NPHs (earthquake, wind and flood) for all DOE facilities, and (3) NPH requirements appropriate for facility characteristics and objectives within a graded approach.
- DOE Order 5481.1B, *Safety Analysis and Review System,* establishes uniform requirements for preparation and review of safety analyses. This order initially applied to all DOE facilities, but is now only applicable to non-nuclear facilities. Safety analyses for nuclear facilities are covered by DOE Order 5480.23.
- DOE Order 5700.6C, *Quality Assurance,* establishes quality assurance requirements and procedures for DOE activities.
- DOE Order 6430.1A, *General Design Criteria,* contains provisions for design and construction of DOE facilities. It does not reference DOE Order 5480.28 because 5480.28 is more recent.
- DOE-STD-1020, *Natural Phenomena Hazards Design and Evaluation Criteria for DOE Facilities,* specifies design and evaluation criteria for the mitigation of NPH effects and conforms to NPH mitigation requirements of DOE 5480.28. DOE-STD-1020 supersedes UCRL-15910, *Design and Evaluation Guidelines for DOE Facilities Subjected to Natural Phenomena Hazards.*
- DOE-STD-1021, *Natural Phenomena Hazards Performance Categorization Criteria for Structures, Systems, and Components,* provides criteria for selecting performance categories (PCs) of structures, systems, and components (SSCs) in accordance with DOE Order 5480.28.
- DOE-STD-1022, *Natural Phenomena Hazards Site-Characterization Criteria,* provides criteria for developing site characterization data to provide site-specific information needed for implementing DOE Order 5480.28.
- DOE-STD-1023, *Natural Phenomena Hazards Assessment Criteria,* provides criteria for the NPH assessments to be conducted to ensure that adequate design

STANDARDS

DOE Standards	National, Federal, and Industry Codes and Consensus Standards
DOE-STD-1020	Model Building Codes; UBC, NBC, SBC
DOE-STD-1021	NEHRP Provisions, FEMA 178 & 222
DOE-STD-1022	ASCE 4 and 7
DOE-STD-1023	ACI, AISC, ASME
DOE-STD-1024	NFPA, ASTM, ANSI, AWS
	SEAOC Blue Book
	NIST, ICSSC RP-4

GUIDANCE / REFERENCES

DOE Manuals for Seismic Safety	National, Federal, and Industrial Resource Documents
Seismic Safety Manual	SQUG/EPRI GIP
Suspended Ceilings	NUREG 0800
Walkdown Guide	DOD Manuals
Seismic Hazard Studies	ATC Manuals, 14, 22
Structural Details	FEMA Manuals
Equipment Tiedowns	NIST, ICSSC RP-3
Basis for Seismic Provisions	

Fig. 4a-2. Standards and guidance used by DOE.

basis load levels are established to comply with DOE Order 5480.28.

- DOE-STD-1024, *Guidelines For Use of Probabilistic Seismic Hazard Curves at Department of Energy Sites,* provides interim guidance on how studies developed by the Lawrence Livermore National Laboratory and the Electric Power Research Institute (EPRI) should be used to assess seismic issues for DOE sites east of 104W.

- DOE-STD-3009, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports.*

The following discussion expands on the provisions of *Presidential Executive Orders* 12699 and 12941; DOE Order 5480.28, *Natural Phenomena Hazards Mitigation;* DOE Order 6430.1A, *General Design Criteria;* and DOE-STD-1020, *Natural Phenomena Hazards Design and Evaluation Criteria for DOE Facilities.*

Presidential Executive Orders

The Earthquake Hazards Reduction Act of 1977 (Public Law 95-124, as amended) was enacted by Congress to reduce risks to life and property from future earthquakes in the United States through the establishment and maintenance of an effective earthquake hazards reduction program. The *National Earthquake Hazards Reduction Program* (NEHRP) was created in response to this Act. Executive Order 12699, *Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction,* was prepared by the Interagency Committee on Seismic Safety in Construction (ICSSC) to implement certain provisions of the Earthquake Hazards Reduction Act. It was signed by President Bush on January 5, 1990.

The objectives of the Executive Order 12699 given in its Sections 1 and 2, are as follows:

> Section 1, New Federal Buildings: "The purposes of these requirements are to reduce risks to the lives of occupants of buildings owned by the Federal Government and to persons who would be affected by the failures of Federal buildings in earthquakes, to improve the capacity of essential Federal buildings to function during or after an earthquake, and to reduce earthquake losses of public buildings, all in a cost effective manner."
>
> Section 2, Federally Leased, Assisted or Regulated Buildings: "The purposes of these requirements are to reduce risks to the lives of persons who would be affected by earthquake failures of federally assisted or regulated buildings, and to protect public investments, all in a cost-effective manner."

The Earthquake Hazards Reduction Act of 1977 was amended by Public Law 101-614, to require the President to adopt standards for assessing and enhancing the seismic safety of *existing* buildings constructed for or leased by the Federal Government which were designed and constructed without adequate seismic design and construction standards.

Executive Order 12941, *Seismic Safety of Existing Federally Owned or Leased Buildings,* signed by President Clinton on December 1, 1994, adopted minimum standards developed by the ICSSC to mitigate unacceptable seismic risks in those buildings.

Executive Order 12941 requires each federal agency to submit cost estimates to the *Federal Emergency Management Agency* (FEMA) for mitigating unacceptable seismic risks in its buildings within 4 years (by December 1, 1998). FEMA, in consultation with ICSSC, is then to report to Congress about how to achieve seismic safety in these buildings in an economically feasible manner. Thereafter, FEMA is to report to Congress on the implementation of Executive Order 12941 on a biennial basis. ICSSC is to update the minimum standards within two years of the publication of the first edition of FEMA's *Guidelines for Seismic Rehabilitation of Buildings and Commentary* and at least every five years thereafter.

DOE Order 5480.28 Natural Phenomena Hazards Mitigation

DOE Order 5480.28 establishes policy for design, construction, and operation of DOE facilities so that workers, the general public, and the environment are protected from the impacts of natural phenomena hazards on DOE facilities. The goals of the Order are to achieve the following goals in a cost-effective manner:

- Provide for safe workplaces
- Protect against property loss or damage
- Provide for continued operation of essential facilities
- Provide for continued public health
- Protect the environment against exposure to hazardous materials.

Order 5480.28 establishes DOE policy and requirements for mitigation of natural phenomena hazards (NPH), including seismic, wind, and flood, for all DOE sites and facilities, using a graded approach.

Its requirements cover:

- Assessment of NPHs for new and existing buildings
- Natural phenomena effects to be considered
- Design of new facilities
- Evaluation and upgrade of existing facilities
- Design of additions and modifications
- Target performance goals
- Graded approach and performance categories
- Interaction and common cause effects
- Instrumentation
- Evaluation of NPH events and lessons learned.

DOE Order 6430.1A General Design Criteria

DOE Order 6430.1A implements the policies of DOE Order 5480.1B, *Environment, Safety, and Health*, and DOE Order 5481.1B, *Safety Analysis and Review System*. DOE Order 5480.28, *Natural Phenomena Hazards Mitigation*, is not referenced in 6430.1A because it is more recent.

DOE Standards, Guidance, and practices are developed and promulgated by DOE 6430.1A to provide a level of design for occupant life-safety, reduction in loss of government property, continued functioning of essential operations, and confinement of hazardous material.

For *Standard Occupancy Structures* and *Essential Facilities*, DOE Order 6430.1A references the seismic requirements of the *Uniform Building Code* (UBC). Recent evaluations under ICSSC procedures have found that the standards used by DOE (DOE-STD-1020) for design and evaluation of buildings are *substantially equivalent* to the *NEHRP Provisions* developed by ICSSC for use under Executive Order 12699 and are substantially more conservative for levels of design beyond those judged acceptable for life safety.

DOE Order 5480.28 does not supersede DOE Order 6430.1A requirements related to seismic and other natural phenomena hazard mitigation, but governs where there are inconsistencies between these two Orders.

DOE-STD-1020 Natural Phenomena Hazards Design and Evaluation Criteria for DOE Facilities

DOE-STD-1020 is the primary reference for structural engineers performing design and evaluation of Structures, Systems, and Components (SSCs) for conformance with DOE Order 5480.28.

DOE-STD-1020 was developed from and supersedes the 1990 version of UCRL 15910, *Design and Evaluation Guidelines for DOE Facilities Subjected to Natural Phenomena*

Hazards, which was originally specified for use by DOE 6430.1A, *General Design Criteria.*

The earthquake design and evaluation criteria provided in DOE-STD-1020 set forth procedures for achieving the performance goals specified in DOE Order 5480.28. These criteria are intended to result in uniform design and evaluation for protection against NPH at all DOE sites. The goal is to ensure that DOE facilities can withstand the effects of natural phenomena hazards, such as earthquakes, extreme winds, tornadoes, and floods. These criteria control the level of conservatism introduced in the design/evaluation process so that all NPH (earthquake, wind, and flood) are treated on a reasonably consistent and uniform basis.

Fig. 4a-3 illustrates the flow of steps through DOE Orders and Standards to determine NPH design criteria for SSCs.

DOE-STD-1020 criteria also employ a graded approach by ensuring that the level of conservatism and rigor in design/evaluation is appropriate for facility characteristics, such as importance, cost, and hazards to people on and off site and to the environment.

For each NPH covered, these criteria generally consist of the following:

- Performance categories and target performance goals
- Specified probability levels for which NPH loadings on structures, equipment, systems, and components must be developed
- Design and evaluation procedures to evaluate response to NPH loads and criteria to assess whether or not the computed response is permissible.

Seismic performance goals are related to the annual probability of exceedance of acceptable behavior limits for structures and equipment as a result of earthquakes. Different criteria are provided for each of four performance categories, each of which has a specified performance goal. Performance categories and performance goals range from *Standard Occupancy Structures* (the lowest seismic occupancy category in the UBC) to highly hazardous occupancy uses (approaching nuclear power plant provisions).

Earthquake design and evaluation criteria in DOE-STD-1020 are aimed at meeting the performance goals described in Table 4a-1.

For SSCs in Performance Category 1 (PC-1), the primary goal is preventing major structural damage or collapse that would endanger personnel. The cost to repair or replace a SSC or the ability of a SSC to continue to function after an earthquake is not a controlling factor.

SSCs in PC-2 are of greater importance because of mission-dependent considerations. In addition, these SSCs may pose a greater danger to on-site personnel than those in Performance Category 1 because of the type of operations or materials involved. The performance of SSCs in PC-2 should allow only relatively minor structural damage that can be easily and readily repaired following the event, and only minimal interruption to operations. The performance goal is slightly more conservative than that for UBC *Essential Facilities* occupancies (e.g., hospitals, fire and police stations, centers for emergency operations, etc.).

SSCs in Performance Categories 3 and 4 pose potential hazards to public safety and the environment because highly toxic materials may be present. Design goals for these categories are intended to limit SSC damage so that hazardous materials can be controlled and confined, occupants and the public are protected, and the SSC will continue to function during and after the natural hazard occurs. For these performance categories, damage must be confined within specified barriers (e.g., buildings, glove boxes, storage canisters, vaults, and ventilation systems). Filtering and monitoring control equipment must continue to operate effectively in the event of severe earthquakes, winds, or floods.

Design and evaluation criteria are aimed at target probabilistic performance goals that require probabilistic NPH assessments. Design loads are specified from such assessments by developing NPH annual probabilities of

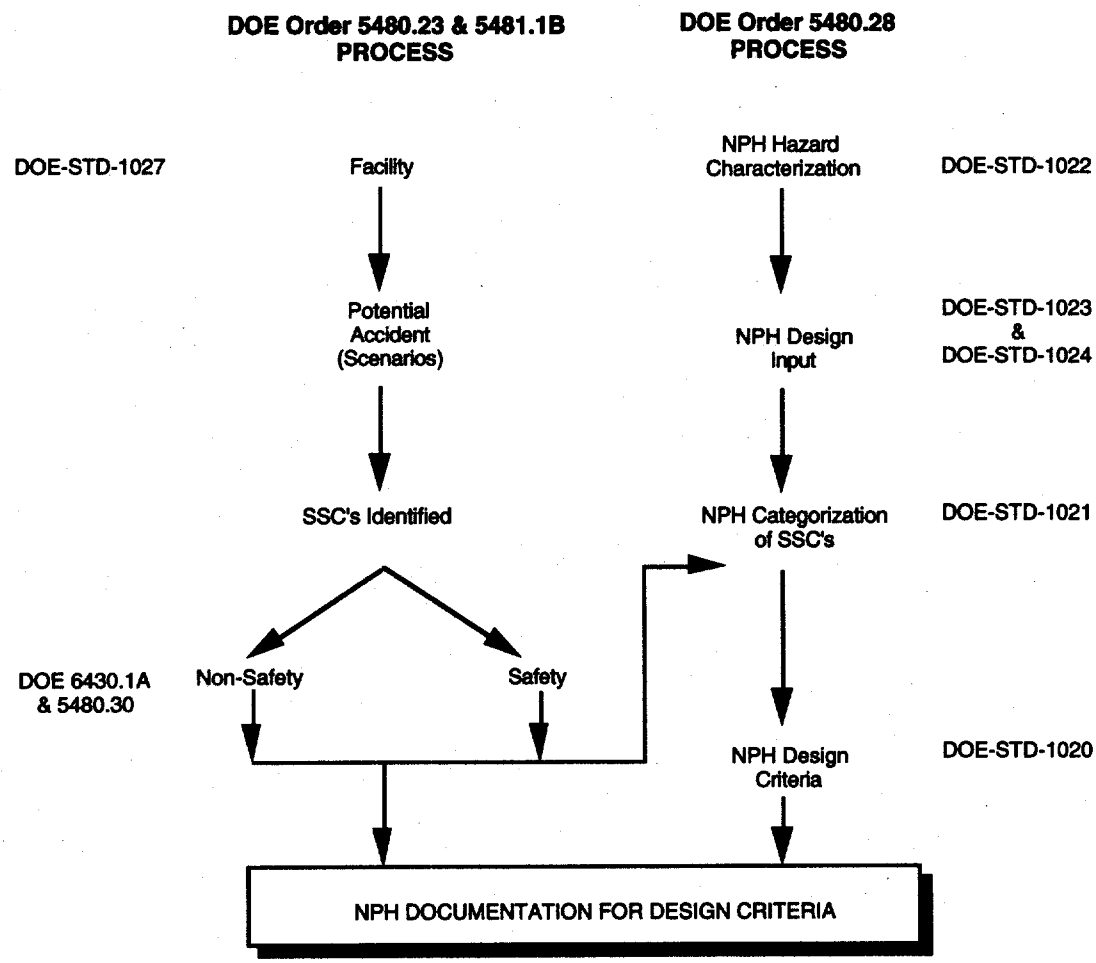

Fig. 4a-3. Flow chart for determining NPH design criteria for SSCs.

exceedance. Table 4a-2 presents target seismic performance goals, seismic hazard exceedance probabilities, and the risk reduction ratios for the four performance categories. Related earthquake return periods are also shown (see DOE-STD-1020 for details).

Performance goals may then be achieved by using the conservatively selected probabilistic loads, combined with deterministic design and evaluation procedures that provide a consistent and appropriate level of conservatism. To ensure that performance of a SSC will meet intended goals, the deterministic details of its design must encompass the potential exceedance of the selected probabilistic input.

Design/evaluation procedures closely conform to standard practices so they are easily understood by most engineers.

DOE Guidance Documents, Courses, Workshops, and Conferences

DOE has prepared a number of guidance documents to support its NPH regulations as shown in Fig. 4a-2. The following manuals are very helpful for design and evaluation of DOE facilities for seismic safety.

Table 4a-1. Seismic performance goals for structures, systems, and components (SSCs)[1] for various performance categories.

Performance Category	Performance goal description	Seismic target performance goal, annual probability of exceeding acceptable behavior limits
0	No precautions for safety, mission, or cost required	No requirements
1	Maintain occupant safety	$\simeq 10^{-3}$ of the onset of SSC damage to the extent that occupants are endangered
2	Occupant safety, continued operation with minimum interruption	$\simeq 5\text{x}10^{-4}$ of SSC damage to the extent that the component cannot perform its function
3	Occupant safety, continued operation, hazard confinement	$\simeq 10^{-4}$ of SSC damage to the extent that the component cannot perform its function
4	Occupant safety, continued operation, confidence of hazard confinement	$\simeq 10^{-5}$ of SSC damage to the extent that the component cannot perform its function

(1) SSC refers to structure, distribution system, or component (equipment).

Table 4a-2. Seismic performance goals and specified seismic hazard probabilities.

Performance category PC	Target seismic performance goal		Seismic hazard exceedance		Risk reduction ratio, R_R
	Probability P_F	Return period, yrs	Probability P_H	Return period, yrs	
1	$1\text{x}10^{-3}$	1,000	$2\text{x}10^{-3}$	500	2
2	$5\text{x}10^{-4}$	2,000	$1\text{x}10^{-3}$	1,000	2
3	$1\text{x}10^{-4}$	10,000	$5\text{x}10^{-4}$ $(1\text{x}10^{-3})$[1]	2,000 (1,000)[1]	5 (10)[1]
4	$1\text{x}10^{-5}$	100,000	$1\text{x}10^{-4}$ $(2\text{x}10^{-4})$[1]	10,000 (5,000)[1]	10 (20)[1]

(1) For sites such as LLNL, SNL-Livermore, SLAC, LBL, and ETEC, which are near tectonic plate boundaries.

- UCRL-CR-106554, *Structural Concepts and Details for Seismic Design*, Lawrence Livermore National Laboratory, Livermore, California, September 1991.

- UCRL-15815, *Practical Equipment Seismic Upgrade and Strengthening Guidelines*, Lawrence Livermore National Laboratory, Livermore, California, September 1986.

- UCRL-15714, *Suspended Ceiling Systems Survey and Seismic Bracing Recommendations*, Lawrence Livermore National Laboratory, Livermore, California, August 1985.

DOE Headquarters, Office of Risk Assessment and Technology, working with Lawrence Livermore National Laboratory, has sponsored many courses, workshops, and conferences that have resulted in valuable notes and conference proceedings. Some are listed below.

- Notes on *Short Course on Seismic Base Isolation* held in Berkeley, California, in 1992.

- Notes on *Walkdown Procedures To Mitigate Natural Phenomena Hazards*, workshops held at various locations in the United States.

- Notes from *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*, workshops held at various locations in the United States.

- *Conference Proceedings* from DOE Natural Phenomena Hazards Mitigation Conferences held at Las Vegas, Nevada, 1985; Knoxville, Tennessee, 1989; St. Louis, Missouri, 1991; Atlanta, Georgia, 1993; and Denver, Colorado, 1995.

Chapter

4b

DOE Natural Phenomena Hazards Mitigation Requirements and Standards

James R. Hill
Robert C. Murray

Natural Phenomena Hazards Mitigation Order DOE 5480.28

As part of a coordinated effort to ensure proper performance of DOE facilities subjected to natural phenomena hazards (NPH), *Natural Phenomena Hazards Mitigation* Order DOE 5480.28 (Ref. 1) was developed to establish:

- Policy requirements for mitigation of NPHs at DOE facilities
- Requirements consistent with building codes and national standards, including the *National Earthquake Hazards Reduction Program* (NEHRP) *Provisions*, for all DOE facilities
- NPH protection requirements appropriate for facility characteristics and objectives within a graded approach.

A graded approach is one in which facilities are placed into categories so that the required level of performance is commensurate with:

- The relative importance of the facility to safety and the environment
- The expected magnitude of natural hazards the facility may be subject to
- The importance of the programmatic mission of the facility
- The particular characteristic of the facility
- The cost and replaceability of the facility.

Order DOE 5480.28 embodies the principles incorporated in DOE Order 6430.1A, *General Design Criteria* (Ref. 2), and UCRL-15910, *NPH Design and Evaluation Guidelines* (Ref. 3), which had been in use at DOE facilities for a number of years. Order DOE 6430.1A contains criteria for the design and construction of DOE facilities. DOE 5480.28 does not supercede DOE 6430.1A, but it does decree that its implementing standard DOE-STD-1020-94, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*, supercedes UCRL-15910. In addition, through its implementing standards, it establishes as requirements good practices that have been used at many of the DOE sites. These requirements cover:

- Assessment of NPHs for new and existing sites
- Natural phenomena effects to be considered
- Design of new facilities
- Evaluation and upgrade of existing facilities
- Design of additions and modifications
- Target performance goals
- Graded approach and performance categories
- Interactions (colateral damage) and common cause effects
- Instrumentation.

The goals of Order DOE 5480.28 are to:

- Provide for safe workplaces
- Protect against property loss or damage
- Provide for continued operation of essential facilities
- Protect public health and the environment against exposure to hazardous materials (off-site consequences).

The key DOE NPH standards required to implement the order are listed here and summarized in the text that follows:

- DOE-STD-1020, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities* (Ref. 4).
- DOE-STD-1021, *Natural Phenomena Hazards Performance Categorization Criteria for Structures, Systems, and Components* (Ref. 5).
- DOE-STD-1022, *Natural Phenomena Hazards Site Characterization Criteria* (Ref. 6).
- DOE-STD-1023, *Natural Phenomena Hazards Assessment Criteria* (Ref..7).
- DOE-STD-1024, *Guidelines for Use of Probabilistic Seismic Hazard Curves at Department of Energy Sites* (Ref. 8).

For new facilities, DOE Order 5480.28 became effective in January 1993. For existing facilities, implementation is planned over several years because of resource constraints and programmatic mission considerations. To start the process of evaluating and upgrading existing facilities, the order requires contractors/operators to establish an implementation plan that contains a prioritized schedule for evaluation of current and future NPH mitigation actions. This plan is to be submitted to the DOE Headquarters Program Office within one year after all implementing standards have been issued.

The issuance and implementation of DOE Order 5480.28 provide the framework for meeting Presidential Executive Order 12699 (Ref. 9) for seismic hazard mitigation of new federal facilities. Executive Order 12941 (Ref. 10) requires inventory, screening, and evaluation of existing facilities.

Fig. 4a-1 in Chapter 4a shows documents used in the DOE NPH mitigation program.

Natural Phenomena Hazards Design And Evaluation Criteria DOE-STD-1020

Design and evaluation criteria to implement DOE Order 5480.28 requirements are provided in DOE-STD-1020. The conceptual and technical basis for this standard was developed in UCRL-15910 over several years of use, review, and revision. The basis for the seismic provisions in DOE-STD-1020 are presented in Ref. 11.

The NPH Mitigation Order requires that each DOE facility, including *Structures, Systems, and Components* (SSCs), be assigned to *Performance Categories* (PC) numbered PC-0 through PC-4, each with a qualitative performance goal for behavior (i.e., maintain structural integrity, maintain ability to function, maintain confinement of hazardous materials) and a quantitative target probabilistic performance goal (expressed as an annual probability of exceedance of acceptable behavior limits [i.e., behavior limits beyond which damage/failure is unacceptable]). DOE-STD-1020 provides four sets of NPH design and evaluation criteria (explicit criteria are not needed for PC-0). These criteria range from those provided by model building codes (normal occupancy) for PC-1 to those approaching nuclear power plant criteria for PC-4. Table 4b-1 illustrates how DOE-STD-1020 criteria for the performance categories defined in DOE 5480.28 compare with NPH criteria from other sources.

Design and evaluation criteria in DOE-STD-1020 use deterministic procedures that establish SSC loadings from probabilistic NPH curves; specify acceptable methods for evaluating SSC response to these loadings; provide acceptance criteria to judge whether the computed SSC response is acceptable; and provide detailing requirements so that behavior is as expected, as illustrated in Fig. 4b-1. These criteria are intended to apply equally to the design of new facilities and to the evaluation of existing facilities. In addition, criteria cover buildings, equipment, piping, and other structures and combine probabilistic and deterministic methods to achieve performance goals.

The annual probability of exceedance of SSC damage as a result of a NPH event (i.e., performance goal) is a combined function of the annual probability of exceedance of the event, factors of safety introduced by the design/evaluation procedures, and other sources of conservatism. The ratio of the hazard annual probability of exceedance and the performance goal annual probability of exceedance is called the *risk-reduction ratio*, R_R, in DOE-STD-1020. This ratio establishes the level of conservatism to be employed in the design or evaluation process. For example, if the performance goal and hazard annual probabilities are the same ($R_R = 1$), the design or evaluation approach would introduce no conservatism. However, if conservative design or evaluation approaches are employed, then the hazard annual probability of exceedance can be larger (i.e., more frequent) than the performance goal annual probability ($R_R > 1$). Seismic criteria are provided in DOE-STD-1020 that achieve risk-reduction ratios, R_R, of 2, 5, 10, and 20.

The report entitled *Basis for Seismic Provisions of DOE-STD-1020* (Ref. 11) demonstrates that performance goals are achieved when:

- The design/evaluation basis earthquake is defined from probabilistic seismic hazard curves, and
- Conservatism in acceptance criteria results in less than 10% probability of unacceptable performance at a *Scaled Design Basis Earthquake* (SDBE).

The SDBE probabilistic definition is used to account for the potential wide variation in site-specific seismic hazard curve slopes, while using a single deterministic acceptance criterion for the range of all potential hazard curve slopes. DOE-STD-1020 encourages obtaining site-specific probabilistic NPH assessments, and requires them for facilities assigned to PC-3 and higher. The required factor of safety, F_R, to achieve risk-reduction ratios, R_R, of 2, 5, 10, and 20 is a function of the hazard curve slope, proximity to tectonic plate boundaries, and uncertainties in seismic capacities of SSCs. For the potential range of hazard curve slopes and capacity variabilities, values of the factors have been evaluated for each desired R_R.

For PCs 1 and 2, the risk-reduction ratio, R_R, of 2 is achieved by F_R of unity which, in turn, is judged to be achieved by following a seismic-acceptance criterion in accordance with the *Uniform Building Code* (UBC). For PC-3 and PC-4, risk-reduction ratios, R_R, are 5 and 10, respectively, except for DOE sites near tectonic plate boundaries where they are 10 and 20, respectively. The required factors for these values of R_R are achieved in the seismic-acceptance criteria by specifying conservative material strengths, structural capacities, inelastic energy-absorption factors, and a seismic scale factor.

DOE-STD-1020 seismic provisions differ from those in UCRL-15910 in that a single value of *Inelastic Energy Absorption Factor*, F_u, is specified for both PC-3 and PC-4, and a scale factor, SF, is used to increase the inelastic demand forces by 1.25 for PC-4 over that required for PC-3. This change was needed because UCRL-15910 specified F_u of 1.0 for brittle modes for both moderate and high-hazard categories. As a result, different performance goals for each category were not achieved for these brittle-failure modes. For PC-4, this change results in slightly more liberal criteria for ductile-failure modes and slightly more conservative criteria for brittle-failure modes.

DOE-STD-1020 also includes damping ratios provided at several response levels to be used in structural evaluations for the purpose of

Table 4b-1. Comparison of performance categories from various sources.

Source	SSC categorization				
DOE-STD-1020	0	1	2	3	4
Uniform Building Code		Standard occupancy structures	Essential facilities		
DOD Tri-Services Manual for Seismic Design for Essential Buildings				High risk	
Nuclear Regulatory Commission				Evaluation of fuel facilities	Evaluation of existing reactors

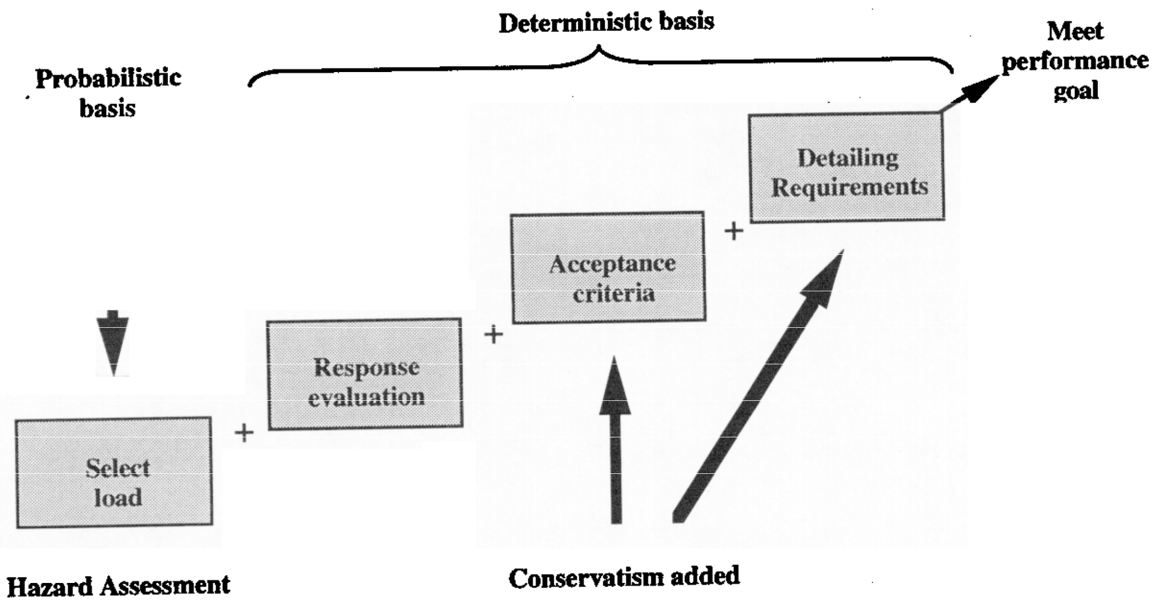

Fig. 4b-1. DOE-STD-1020 combines probabilistic and deterministic methods to achieve performance goals.

determining in-structure response spectra. As well, seismic interaction (colateral damage) is explicitly addressed.

Natural Phenomena Hazards Performance Categorization for Structures, Systems and Components DOE-STD-1021

Safety engineers and facility managers responsible for the design or evaluation of SSCs need to select levels of NPH and corresponding amounts of conservatism in NPH design and evaluation criteria that are appropriate for SSC designs. Design criteria are selected on the basis of the failure consequences of the SSC. For example, if the failure of a large dam may destroy a city, it is likely to be designed for a long recurrence-period precipitation (larger storm). In contrast, because far fewer potential fatalities would result from the collapse of a warehouse roof, that roof may be designed for a much smaller recurrence-period precipitation (smaller storm). Still, if both designs are optimally performed, members of the public will be exposed to relatively the same level of risk from the dam as from the warehouse roof.

To attain similar uniformity in risk from the potential failure of various SSCs that are present in DOE facilities, DOE Order 5480.28 requires that all SSCs be placed in one of the five PCs commensurate with the consequences of failure. Performance goals for these categories are specified in terms of *target* annual failure probabilities. DOE-STD-1021 provides guidelines for placing SSCs into these performance categories. The basic categorization process (excluding system interaction effects) is outlined in the flow chart in Fig. 4b-2.

DOE-STD-1021 uses the results of SSC safety classification, facility hazard classification, and accident analyses that are performed in conformance with other DOE Orders.

Performance Category 4 (PC-4) SSCs are defined as safety class SSCs in facilities with sufficient quantities of radioactive/highly toxic materials and (explosive) energy that, if released, can potentially result in prompt off-site fatalities.

Performance Category 3 (PC-3) SSCs are defined as safety class SSCs in facilities with sufficient quantities of radioactive/highly toxic materials and energy that necessitate on-site emergency planning.

Performance Category 2 (PC-2) SSCs include safety class SSCs in essential facilities or those with sufficient quantities of radioactive materials to be reportable to the Environmental Protection Agency (EPA). Additionally, PC-2 SSCs must perform their emergency functions to preserve the health and safety of those working with hazardous materials and co-located personnel.

Building structures or components with potential human occupancy and SSCs whose failure can potentially cause a life-threatening situation for occupants are placed in PC-1. SSCs that have no effect on safety, mission, or cost need not be designed to withstand NPH loads and may be placed in PC-0.

Problems of system interactions (colateral damage) caused by seismic shaking are important, but often overlooked. Therefore, DOE-STD-1021 places special emphasis on the consideration of system interaction effects in the process of NPH categorization. Simple-to-use, but conservative, rules are provided to preclude adverse effects of lower category SSCs (sources) that may impact on or damage higher category SSCs (targets). These rules satisfy the basic requirement that the performance goal of the target SSCs must not be compromised. Several examples are provided in DOE-STD-1021 to illustrate the use of the interaction rules.

Natural Phenomena Hazards Site Characterization Criteria DOE-STD-1022

The purpose of this standard is to provide criteria for developing site characterization and identifying site-specific information needed for design and evaluation of DOE facilities subject to natural phenomena hazards. The standard covers geologic, seismologic, geotechnical, hydrologic, and meteorologic aspects of site characteristics. The seismic-related hazards include site earthquake ground shaking; tectonic site deformation; ground failure induced by ground shaking including liquefaction, differential compaction, and landsliding; and earthquake-induced flooding.

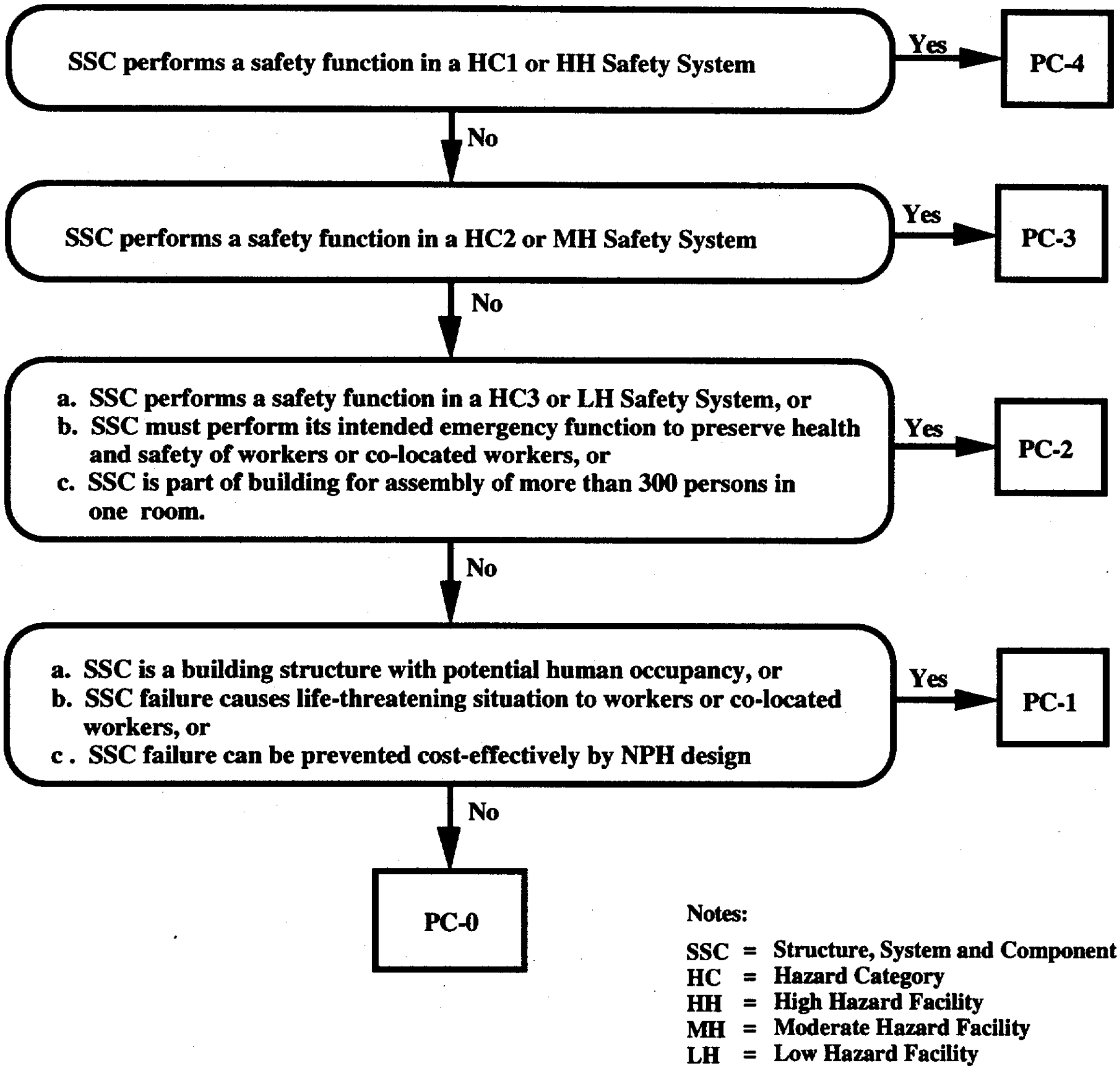

Fig. 4b-2. Basic criteria for preliminary NPH performance categorization of structures, systems, and components.

Considerations of geologic and seismologic aspects include identifying and characterizing seismic sources and resulting site ground motions, evaluating the potential for tectonic and other site deformation, and earthquake-induced flooding, and evaluating volcanic hazards. Major considerations of geotechnical aspects involve defining site soil properties needed for hazard evaluation and seismic engineering analyses, evaluating site soil-amplification effects on ground motions, conducting seismic soil-structure interaction analyses, and evaluating the potential for site ground failure induced by ground shaking.

Hydrologic and meteorologic aspects of site characterization criteria also are important. Site studies of hydrologic aspects include determination of ground-water conditions, flood runoff, drainage, and other hydrologic characteristics that could influence the design or operation of DOE facilities. Ground-water conditions include ground-water levels, flow patterns, permeability, porosity, and hydraulic gradients at the site, as well as the chemical analysis of the ground water. Site studies on meteorologic aspects should be performed to provide sufficient information for the design and evaluation basis of wind and tornado hazards.

Seasonal weather conditions of the local site and region, including temperature, precipitation, relative humidity, and prevalent wind direction, need to be determined. The occurrences and intensity of heavy rain, snow, ice storms, and thunderstorms, as well as strong wind, tornadoes, and hurricanes, need to be determined.

The scope and degree of detail of investigations to address these natural hazards depend on several factors, including the hazard classification of the facilities; the subsurface conditions at the site; the seismologic, hydrologic, and meteorologic environments of the site region; and the extent of prior knowledge, investigations, and data regarding the site and site region. An appropriate scope of investigation should be developed for a particular facility after considering all these factors. For example, although more detailed investigations are generally appropriate for facilities having higher hazard classifications, investigations of lesser scope and detail may be appropriate when existing knowledge of the site and region is relatively high. Similarly, although less-detailed investigation would generally be commensurate with lower-hazard facility classification, more comprehensive investigations may be needed if investigations to define the hazards have not been conducted previously.

Natural Phenomena Hazards Assessment Criteria Standard DOE-STD-1023

DOE Order 5480.28 requires a probabilistic assessment of the likelihood of future NPH occurrence. The level of probabilistic NPH assessment to be conducted must be appropriate for the performance category being considered, consistent with the graded approach. For sites containing facilities with SSCs in PC-3 and PC-4, a site-specific probabilistic NPH assessment must be conducted. For sites containing facilities with SSCs in PC-1 and PC-2 only and having no site-specific probabilistic NPH assessment, it is sufficient to utilize NPH maps from model building codes or national consensus standards.

DOE Standard DOE-STD-1023 provides criteria for NPH assessments to ensure that adequate design-basis loadings are established for design and/or evaluation of DOE facilities. It provides general assessment criteria for all NPHs, as well as specific criteria for the assessment of seismic hazard, wind, tornado, and flood. The emphasis is on site-specific probabilistic NPH assessment, i.e., development of NPH curves. Criteria for development of design response spectra to define the seismic input motion are also provided.

There are five steps in probabilistic seismic hazard assessments, as shown in Fig. 4b-3. These include:

a. Development of zonation maps around the site indicating faults and seismic source areas

b. Development of recurrence relations indicating how many earthquakes of specific magnitude are possible in each source area. Zonation and recurrence are developed by seismicity experts

c. Attenuation relationships indicating peak ground acceleration for earthquakes of specified magnitude as a function of distance from the source. These are developed by ground motion experts

d. The above information is combined probabilistically to develop seismic hazard curves showing *Peak Ground Acceleration* (PGA) as a function of *Probability of Exceedence* (PE). Uncertainity in the parameters is included

e. In addition to the hazard curve, response spectra showing the frequency content of the expected ground motions also are developed.

Guidelines for Use of Probabilistic Seismic Hazard Curves at Department of Energy Sites DOE-STD-1024

This standard provides guidance in the use of seismic hazard curves developed by the Lawrence Livermore National Laboratory (LLNL) and the Electric Power Research Institute (EPRI) for estimating seismic hazards at DOE sites in the eastern United States (East of longitude 104W).

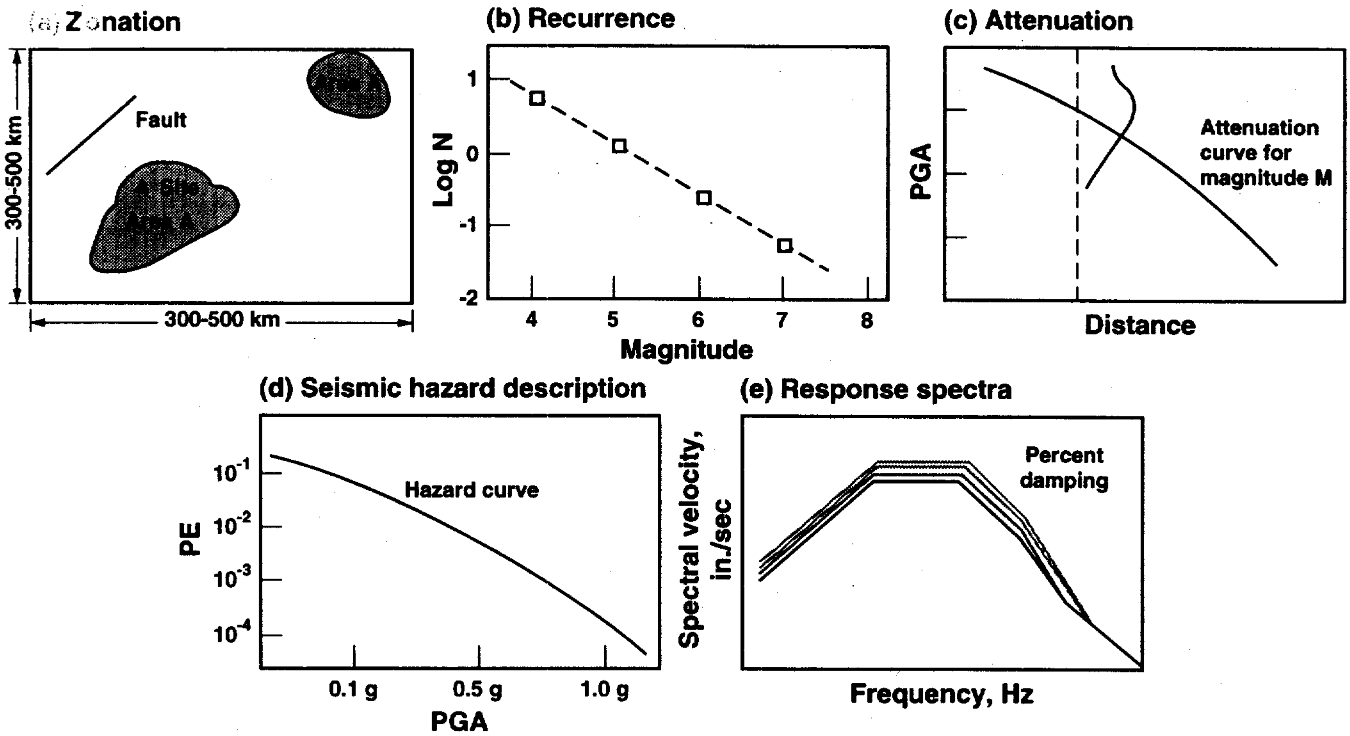

Fig. 4b-3. Steps in probabalistic seismic hazard assessment.

References

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